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VERTICAL DISTRIBUTION OF FUEL IN SPRUCE-FIR LOGGING SLASH

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JAMES K. BROWN received his bachelor's degree from the University of Minnesota in 1960, his master's from Yale University in 1961, and his Ph. D. from the University of Michigan in 1968, all in forestry. From 1961 to 1965 he did research on field measurement of fuel properties and fire-danger rating systems while with the Lake States Forest Experiment Station. In 1965 he transferred to the Northern Forest Fire Laboratory, Missoula, Montana, where he is responsible for research on the physical properties of fuel.

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ABSTRACT

About 70 percent of the volume and surface area of spruce-fir logging slash lies below the mid-depth of the slash. Material 0 to 1 centimeter in diameter was distributed vertically in the same proportions as all other material. Old slash in the first 20 centimeters above the ground contained a higher proportion of large material than new slash. Quantity of slash averaged 26.5 kg./m.^{2} (118 tons/acre) dry weight with 0.57 kg./m.^{2} composed of material 0 to 1 centimeter in diameter. Bulk density of slash decreased vertically and averaged 0.030 g./cc. for new slash and 0.053 for old slash. Needle mats suspended in the slash occurred with a 40 percent frequency.

INTRODUCTION

The flammability of logging slash depends largely on its physical properties such as fuel volume, surface area, weight, porosity, and size distribution of particles. Quantitative knowledge of these properties will aid in understanding and predicting fire behavior in slash. However, quantitative information describing many of the physical properties of slash is lacking, especially in regard to vertical distribution of volume and surface area.

Presented in this paper are results of a study that quantitatively determined fuel volume, surface area, bulk density, and the ratio of void volume of fuel complex to fuel surface area (λ) at different vertical levels within logging slash. Also discussed are loading (weight per unit area), percent composition of slash by particle sizes, existence of suspended needle mats, and methods of measurement.

This study is part of a fire research effort to quantitatively describe the properties of fuels and develop a means of relating these fuel properties to fire behavior. As this knowledge accumulates it will be used to formulate and improve a system for quantitatively appraising forest and range fuels.

Major findings of the study were:

1. Volume, surface area, and bulk density decrease from the ground up. Slightly over two-thirds of the total volume and surface area was in the lower half of the slash.

2. The total material in small-sized slash is distributed vertically in approximately the same proportions as in all-sized slash.

3. Aging of slash for 6 months to 1 year greatly reduced the amount of needle volume and surface area.

4. An average of 80 percent of the total slash volume in the study was comprised of material over 10 centimeters in diameter; this material would probably contribute relatively little energy to rate of spread and intensity of a fire front.

5. Mats of needles frequently were suspended in the slash and probably contribute to the flammability of aged slash.

METHODS

The area[1] chosen for study had been clearcut and was located on the Tally Lake Ranger District, Flathead National Forest. Trees in the study area (marked off in 10-acre blocks) were mostly Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), Engelmann spruce (*Picea engelmannii* Parry), and western larch (*Larix occidentalis* Nutt.). Eight blocks were selected so that north, east, south, and west aspects were equally represented; the blocks were sampled in July 1968. Also, the blocks were selected to furnish two age classes of slash separated by 4 to 7 months (table 1). Slash on different aspects and of different ages was sampled to increase the range of conditions examined and not to isolate the effects of aspect and age on the fuel properties.

The physical fuel properties were determined separately (from ground to top of slash) for 20-centimeter thick horizontal strata. A planar intersect technique, a

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[1]This area is the site of a cooperative study on the use of fire in silviculture; cooperating in the study are the USDA Forest Service, Northern Region and Intermountain Forest and Range Experiment Station.

Table 1.--*Age of slash at time of measurement*

Old slash			New slash		
Aspect and Block	Date slashing completed	Age	Aspect and Block	Date slashing completed	Age
		Months			*Months*
South-10	5/31/67	12½	South-11	10/25/67	8
North-13	7/16/67	11½	East-5	11/16/67	7½
West-11	7/11/67	11½	East-4	11/17/67	7½
			North-10	2/7/68	5
			West-13	2/14/68	5
	Average	12		Average	6½

modification of the line interception technique,[2] provided the basis for estimating fuel volume and surface area. In using the planar intersect technique, 15 sampling planes that were 30 centimeters wide and as high as the slash were systematically located along transects in each of the eight blocks. The sampling planes were established on the ground parallel to contours of the slope by delineating the sides with metal rods plumbed vertically and spaced 30 centimeters apart (figure 1).

Figure 1.-- Pairs of metal rods, sharpened at one end, were stuck in the ground, plumbed vertically and braced 30 centimeters apart to delineate the sampling planes. Extremes in the amount of slash encountered are shown.

[2]R. H. Canfield. Application of the line interception method in sampling range vegetation. J. Forestry 39: 388-394. 1941.

The bottoms of the sampling planes were delineated by the top of the forest floor and the tops of the planes by the highest particle passing between the sides of the planes. Depth of slash was measured to the nearest centimeter, but forest floor litter was excluded from measurements. The vertical sampling planes were divided into strata 20 centimeters deep and the number of branch particles intersecting the planes recorded by strata and the following particle diameter classes: 0-1, 1-3, 3-10, and over 10 centimeters. Intersections by species were kept separate for the 0-1 size class. Particle diameters appearing borderline between classes were checked with a go-no-go gage.

Calculations

Volume of branchwood was calculated from:

$$V = L\left(\frac{nd^2\pi^2}{8}\right)$$

where V = Volume, $cm.^3$

L = Length of fuel complex perpendicular to sampling plane--set at 1 cm.

n = Number of particle intercepts

d = Average diameter of size class, cm.

Derivation of the formulas and theory and application of the technique are discussed further by Brown,[3] Beaufait,[4] and Van Wagner.[5]

Average diameter of the 0-1 centimeter size class was determined for a large sample of branches randomly collected from the study area. Branch diameters were measured every 10 centimeters beginning at a point 1 centimeter in diameter and continuing to and including the tips of all branchlets. The average was weighted by distance between measurements which was usually less than 10 centimeters for the tip measurements. Average diameter for the 1-3 and 3-10 size classes was determined by running transects through slash on all exposures and measuring diameters of all branches between 1 and 10 centimeters in diameter falling under the transect. Where pieces of slash over 10 centimeters in diameter intersected the sampling planes, they were measured individually and handled separately in the volume equation; thus, determination of an average diameter for these larger pieces was unnecessary.

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[3] J. K. Brown. A planar intersect method for sampling fuel volume and surface area. Forest Sci. (in press).

[4] W. R. Beaufait. Prescribed fire cooperative study--Region 1-INT. (Study Plan No. 2102-12 on file at Intermountain Forest & Range Exp. Sta., Northern Forest Fire Laboratory, USDA Forest Serv., Missoula, Mont.) 1967.

[5] C. E. Van Wagner. The line intersect method in forest fuel sampling. Forest Sci. 14(1): 20-26, illus. 1968.

Volume of needles was calculated by summing the following formula over all tree species:

$$Vn = (V_b \rho_b cp)/\rho n$$

where Vn = Needle volume, cm.^{3}

V_b = Volume of branchwood 0-1 cm. in diameter, cm.^{3}

ρ_b = Density of branchwood 0-1 cm. in diameter, g./cm.^{3}

c = Needle weight (g.) per gram branchwood 0-1 cm. in diameter

p = Proportion of foliage attached to slash

ρ_n = Density of needles, g./cm.^{3}.

This formula determines the amount of needle volume per unit of branchwood volume. The planar intersect method furnished values of branchwood volume for use in the formula. Weight of needles per gram of branchwood was estimated by stripping needles from samples of branchwood (under 1 centimeter in diameter) and weighing the needle and branch components. The proportion of foliage attached to branches was ocularly estimated by species as the percent of total possible needles assuming no needle-fall had occurred. A mercury pycnometer was used to obtain the density values.

Surface area of branchwood was calculated from:

$$S = L\left[\frac{8.238\ nd}{2}\right]$$

where S = Surface area, cm.^{2}.

Surface area of needles was determined by species from the product of needle volume and needle surface area-to-volume ratio.[6]

RESULTS AND DISCUSSION

Density of foliage must be known prior to calculation of fuel volume and surface area. Density of foliage for all species averaged 0.55 gram per cubic centimeter. Density of branchwood, determined from particles in the 0-1 size class for all species, averaged 0.50 gram per cubic centimeter. The proportion of foliage attached to branches averaged 9 percent for old slash and 38 percent for new slash. Other fuel characteristics required for the calculations are in table 2.

Volume and Surface Area

Fuel volume was concentrated in the lower portions of the slash. About 68 percent of the total volume was below the average mid-depth of the slash (figure 2). Generally, there seemed to be only minor differences in volume between the small- and large-size material and between the old and new slash sampled at various heights above ground (table 3). These results indicate that the small-size material is distributed vertically in about the same proportions as all slash material. However, volume of old slash in the first 20 centimeters above ground comprised 52 percent of the total volume, which is noticeably greater than the 34 percent for new slash. The large proportion of old slash volume in the first 20 centimeters above ground was due to the presence of material over 1 centimeter in diameter.

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[6] J. K. Brown. Ratios of surface area to volume for common fire fuels. Forest Sci. 16(1): 101-105. 1970.

Table 2.--*Average diameters, needle weights per gram of 0-1 centimeter diameter branchwood, and needle surface area-to-volume ratios for the different species in the slash*[1]

Species	Diameters 0-1 cm.	Diameters 1-3 cm.	Diameters 3-10 cm.	Needle weight per gram branchwood	Needle surface area-to-volume ratio
	Cm.	*Cm.*	*Cm.*	*G./g.*	*Cm.^{2}/cm.^{3}*
Douglas-fir and subalpine fir	[2]0.219	1.63	5.27	[2]1.49	69.1
Spruce	[2].195	1.90	4.76	[2]1.38	54.2
Larch	[2].260	1.82	4.36	[2].19	184.0
Lodgepole pine	.432	1.76	4.88	1.43	64.7
Average[3]	.224	1.74	5.02		

[1]Averages were based on 20 to 250 observations.
[2]Data acquired by W. R. Beaufait as a part of the cooperative study.
[3]Averages were weighted by the total number of sampled intersections for each species.

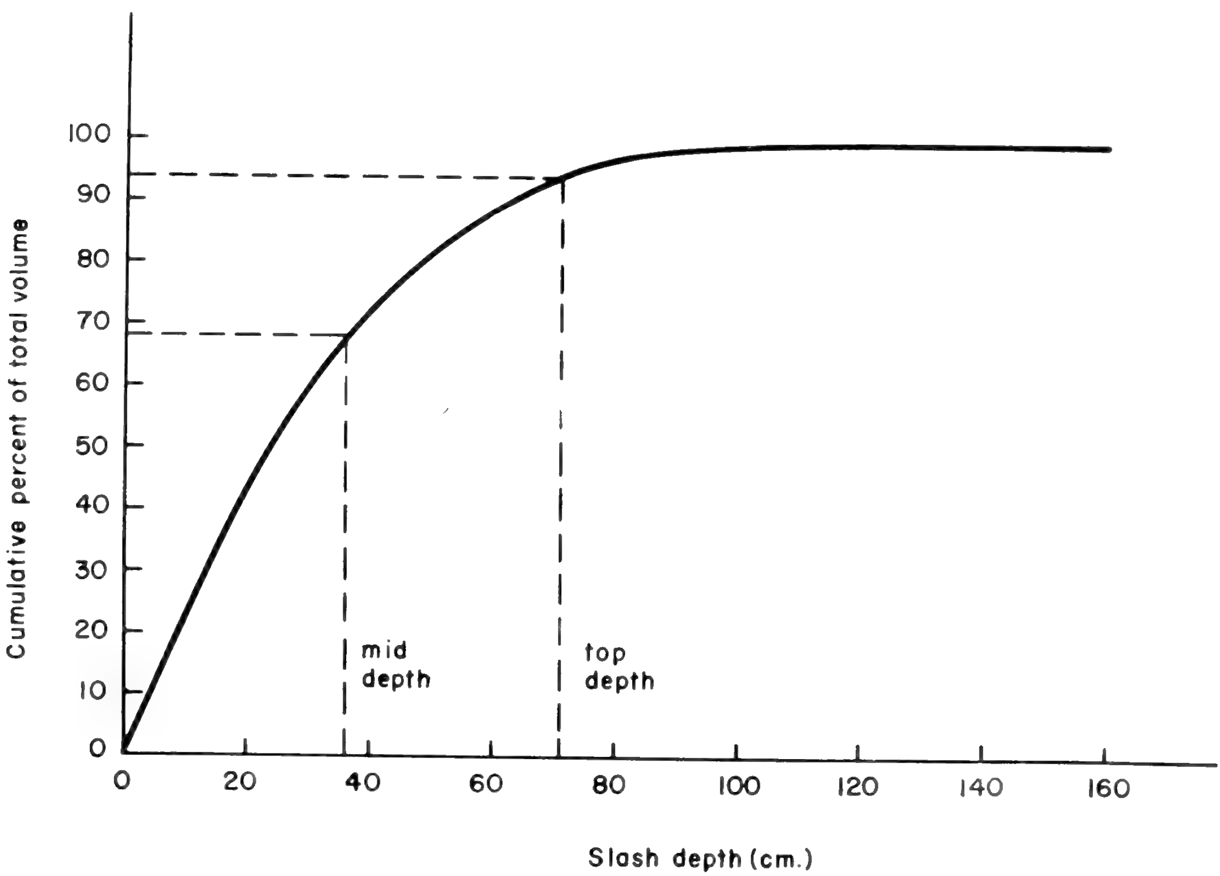

Figure 2.--Cumulative percent of total old and new slash volume at different slash depths. Top depth is the average of all depth measurements and mid-depth is one-half of the top depth.

Table 3.--*Percent of total slash volume by slash age, size, and height above ground*

Height of slash	All-size slash			0-1 cm.-size slash		
	Old	New	Old and new	Old	New	Old and new
Cm.	*Percent*					
0-19	52	34	43	47	48	48
20-39	23	38	30	32	28	29
40-59	13	19	16	12	14	14
60-79	12	5	9	4	3	3
80-99	<1	4	2	2	4	3
100-119	<1	<1	<1	2	1	1
120-139	<1	<1	<1	<1	<1	<1
140-159	<1	<1	<1	<1	<1	<1

Fuel surface area, like volume, was concentrated in the lower portions of the slash. About 68 percent of the total surface area was below the average mid-depth of the slash. The relationship between cumulative percent surface area and depth is almost identical to that in figure 2. Differences in the proportions of surface area, between small- and large-size material, and between new and old slash in the same strata, averaged a maximum of three percentage points.

Composition of Slash

The species composition of the slash based on the proportion of all particle intersections with all sampling planes was as follows:

Species	*Percent of total intersections*
Douglas-fir and subalpine fir	55.5
Spruce	32.1
Larch	8.1
Lodgepole pine	4.3
	100.0

The proportions of fuel volume and surface area by different-size material comprising the slash are shown in table 4. The new slash contained considerably larger proportions of volume and surface area in the 0-1 size class than old slash because a larger proportion of needles was attached to the branches in new slash. This is shown in the following tabulation of needle volume and surface area, for all of the plots expressed as a percent of the 0-1 size class volume and surface area:

Slash age	*Average needle volume (percent)*	*Average needle surface area (percent)*
Old	6.4	13.5
New	24.5	41.7

The 0-1 size class provided 79 percent of the fuel surface area in new slash but only 49 percent in the old slash. This large proportion of fine-particle surface area in new slash points out the higher potential flammability of new slash compared to old slash.

Table 4.--*Percent of total fuel volume and surface area comprising the slash by diameter classes*

Diameter size class	Volume: Old slash	Volume: New slash	Surface area: Old slash	Surface area: New slash
Cm.	*Percent*	*Percent*	*Percent*	*Percent*
0-1	1.0	3.8	49.0	79.4
1-3	4.4	7.3	15.0	8.2
3-10	9.3	11.7	11.6	4.7
10+	85.3	77.2	24.4	7.7
	100.0	100.0	100.0	100.0

A practical fuel sampling technique is suggested by the observation that most of the slash volume (77 and 85 percent, table 4) was from material over 10 centimeters in diameter. If estimates of slash volume are desired, line intersect sampling of material over 10 centimeters in diameter probably would provide adequate fuel volume estimates. Aerial photographs might provide an effective, relatively inexpensive format for sampling with the line intersect method.

Loading

Loadings for the eight blocks examined are shown in the following tabulation:

Degree of loading	*All material*		*0-1 cm.-size class*	
	(kg./m.^{2})	*(tons/acre)*	*(kg./m.^{2})*	*(tons/acre)*
Highest	47.3	211	1.24	5.5
Lowest	5.1	23	19	.8
Average	26.5	118	.57	2.6

Bulk Density

Bulk density, a measure of the porosity of a fuel complex, decreased from the ground up through the slash (figure 3). In the lower 20 centimeters of old slash, bulk density was quite high, averaging 0.10 gram per cubic centimeter. This was due to a large volume of material over 1 centimeter in diameter lying close to the ground. Average bulk densities for the entire depth of slash were as follows:

Slash age	*All material*	*0-1 cm.-size class*
	(g./cm.^{3})	*(g./cm.^{3})*
Old	0.053	0.00054
New	.030	.00104

The bulk density of old slash is almost twice that of new slash. This indicates that aging of slash permits compaction even within a few months. In a study of slash from nine conifer species, Fahnestock and Dieterich[7] found that slash depth was reduced by 20 percent in 1 year and 45 percent within 5 years. Bulk density also would be correspondingly reduced, although to a lesser extent than depth because loading would decrease due to decay, at least over a 5-year period.

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[7] G. R. Fahnestock and J. H. Dieterich. Logging slash flammability after five years. USDA Forest Serv., Intermountain Forest & Range Exp. Sta. Res. Pap. 70, 15 p., illus. 1962.

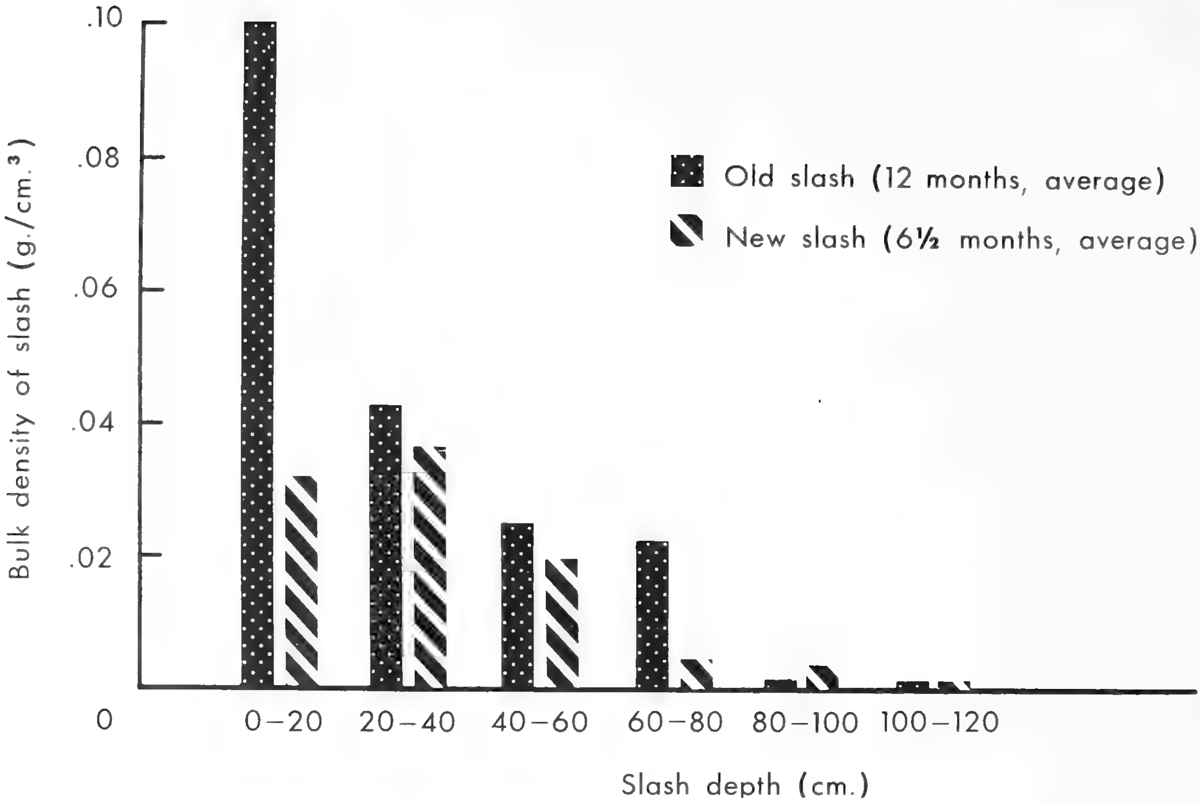

Figure 3.--Bulk density of old and new slash at 20-centimeter depth levels. The average depth was 73 centimeters for old slash and 68 centimeters for new slash.

Void Volume to Surface Area Ratio (λ)

The ratio λ is also a measure of the porosity of a fuel complex and expresses the amount of void space associated with a unit area of fuel surface. Generally, as λ increases, movement of air and other gases is freer because the space between particles is greater. But, at the same time, the distance radiant heat must travel between particles is greater.

In this study, λ increased vertically with old slash generally being more porous as shown in the tabulation below:

Slash depth	*Slash age*	
	Old	*New*
(cm.)	*(cm.^{3}/cm.^{2})*	*(cm.^{3}/cm.^{2})*
0-19	9	6
20-39	14	10
40-59	37	20
60-79	62	93
80-99	283	82
100-119	284	250
120-139	922	454
140-159	1,130	937

Suspended Needle Mats

Suspended needle mats are layers of dead needles formed when needles fall and catch on branches. The branches and trapped needles catch other needles, thus, forming mats. Mats of needles (some bark flakes are also present) may build up to a thickness of 2 or 3 centimeters and resemble small pieces of the forest-floor litter layer suspended within the slash.

Needle mats were recorded intersecting 40 percent of the sampling planes. This is a rather high occurrence of mats since each sampling plane is represented by a line transect 30 centimeters long. Thus, one or more mats were observed on almost every other 30-centimeter-long transect. The average length of mat material lying within a sampling plane was 21 centimeters. The number and size of needle mats did not vary significantly between old and new slash.

The significance of needle mats on the flammability of slash is unknown; however, these mats are probably highly flammable due to their fine particle composition. The formation of needle mats retains fallen dead needles within the slash and prevents their compaction on the ground.

Headquarters for the Intermountain Forest and Range Experiment Station are in Ogden, Utah. Field Research Work Units are maintained in:

Boise, Idaho
Bozeman, Montana (in cooperation with Montana State University)
Logan, Utah (in cooperation with Utah State University)
Missoula, Montana (in cooperation with University of Montana)
Moscow, Idaho (in cooperation with the University of Idaho)
Provo, Utah (in cooperation with Brigham Young University)